557. Radial correction controllers of gyroscopic stabilizer

M. Sivčák[1], J. Škoda[2],
Technical University in Liberec,
Studentská 2, Liberec, Czech Republic
e-mail: [1]*michal.sivcak@tul.cz;* [2]*jan.skoda@pevnosti.cz*

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Abstract. This paper takes up the previous research paper on the considered topic and extends the proportional feedbacks of correction and compensation system by replacing them by PID controllers. The paper presents a part of research of the gyroscopic stabilizer and describes a gyroscopic stabilizer correction and compensation system. Consequently, identification of the effect of correction and compensation system parameters settings for the system behavior is described. Estimation of concrete compensation and correction settings is reported in this study.

Keywords: gyroscopic stabilizer, vibration-isolation, optimization, PID controller

Introduction

A part of the one-axis gyroscopic vibration-isolation platform project is the estimation of the correction and compensation system controllers coefficients (p_1, p_2, i_1, i_2, d_1, d_2). These coefficients represent a PID feedback between the displacement of the gyroscope precession frame or stabilizer frame deflection from the vertical post and the compensation or correction torque. These torques act on the precession frame (correction – p_2, i_2, d_2) and stabilizer frame (compensation – p_1, i_1, d_1). For the determination of the proportional members magnitude of the feedback there was created a mathematical model in the Maple environment. For model verification another mathematical model was constructed in the MapleSim environment. The system motion simulations during step change of transversal acceleration help to identify the impact of the PID feedback coefficients on the system behavior, and it is possible to estimate the concrete magnitude of these parameters by the comparison with desired behavior of mechanical system.

System and description of simulations

Model of system is schematically depicted in Fig. 1. System consists of a foundation (black), which provides three-dimensional general motion (translations in direction of three axes and rotations around these axes). There is a frame (blue) which provides rotational motion around longitudinal axis (its angle displacement is represented by coordinate q_1) mounted on the foundation. The frame is supported by spring and damper, which are mounted between the foundation and the frame and are represented in the model by the torsion spring and damper. Precession frame of the gyroscope (green) is mounted on the frame and provides rotation around transversal axis (its angle displacement represented by coordinate q_2). The gyroscope (pink) with a vertical rotation axis (rotation represented by angle coordinate q_4) is mounted in bearings on the precession frame. Dissipative forces between frame and precession frame are not considered. Dissipative forces between the precession frame and the gyroscope are balanced by gyroscope driving torque. A sensor (yellow) of frames displacement from absolute vertical is mounted on the frame. The sensor is modeled as a mathematical pendulum (its displacement from the frame's normal post is represented by angle coordinate q_3) and there is considered passive resistance in pivot, which is formulated as a small torsional damping. Compensation torque motor (bigger red cylinder) is mounted on the rotation axis of frame between the foundation and the frame and is driven by angular displacement of the gyroscope precession frame. Correction torque motor (smaller red cylinder) is mounted on the precession frame rotation axis between the frame and the precession frame of gyroscope and is driven by signal from the sensor (angular displacement of mathematical pendulum). The sensor or its model pendulum in this system indicates an angular displacement of the frame from absolute vertical post (direction of external accelerations resultant). Torques of correction and compensation motors are as follows:

$$M_{k1} = p_1 q_2(t) + d_1 \frac{d}{dt} q_2(t) + i_1 \int_0^t q_2(\tau)\, d\tau \,, \tag{1}$$

$$M_{k2} = p_2 q_3(t) + d_2 \frac{d}{dt} q_3(t) + i_2 \int_0^t q_3(\tau)\, d\tau \tag{2}$$

and are placed on right hand side of first two Lagrange equations (torque M_{k1} on RHS of equation for $q_1(t)$, M_{k2} on RHS of equation for $q_2(t)$).

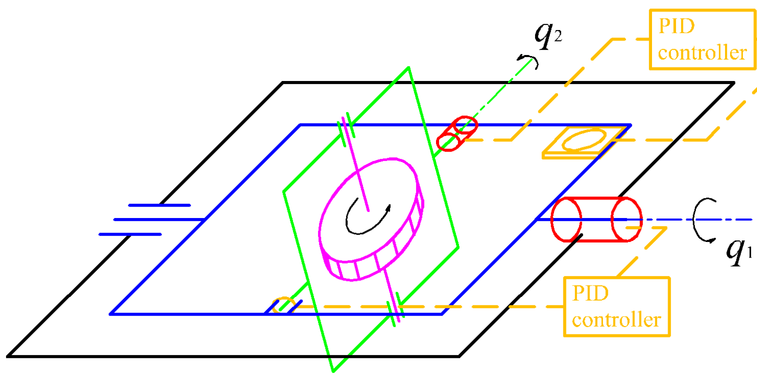

Fig. 1. Scheme of gyroscopic stabilizer model

A numerical experiment was designed for identifying behavior of the system. The time response for excitation by step change of acceleration in transversal direction was observed. This experiment represents centrifugal acceleration during steering maneuver of car for example. If system is excited by transversal the correction system acts on the gyroscope precession frame and is driven by signal from the sensor mounted on the frame. The balancing frame to reach the apparent vertical post (which is direction of gravity and centrifugal accelerations resultant) is purpose of the correction system. If the centrifugal acceleration generates the torque on the frame the correction motor acts torque on the precession frame rotation axis due to deviation of apparent vertical indicated by sensor. Then gyroscope generates the gyroscopic torque around longitudinal axis due to correction torque and consequently frame vertical reaches the apparent vertical. But gyroscope precession frame is displaced due to torque generated by springs which are mounted between frame and foundation. Due to this the compensation system exerts a torque of the same direction as gyroscopic torque on frames rotation axis and helps to accelerate reaching the apparent vertical post.

There are two requirements on a system behavior during steering maneuver. The first is to reach apparent vertical (resultant of gravity and transversal or centrifugal acceleration) of frame as fast as possible. Based on this requirement, there was determined a desired ideal time response of frame displacement (see Fig. 2). The second and very important requirement is that the maximum displacement of precession frame must be less than ±0,5 rad because of its design limits. Only fulfilling these two requirements is satisfactory.

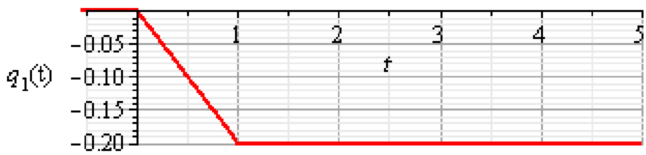

Fig. 2. Desired time response of frame displacement during step change of transversal acceleration from 0 ms^{-1} to 2 ms^{-1}

Results and their interpretation

The criteria function was designed in this research work. Sum of squared differences between desired ideal time response and real time response of frame displacement was chosen as the first criteria. The minimum of this criteria determines good setting of correction and compensation system feedback PID controllers. But it is problematic to obtain these criteria functions in analytical form because the system is nonlinear and of the 9th order. For this reason a large number of numeric simulations for various setting of two PID controllers parameters (others stay constant) was performed and their criteria values were plotted as a three dimensional surface. The minimum of this surface can be observed and there is a possibility to determine optimal setting of those two parameters. By few cycles when the determined parameters from previous cycles remained constant is possible to find optimal setting of those two PID controllers. Determination of stability intervals of tuned parameters is necessary and must be performed for chosen values of coefficients from previous step on start of each step.

There was added a large value to first criteria function when maximal absolute value of precession frame displacement was bigger than 0,5 rad for easier determination when the first criteria is minimal and simultaneously maximal displacement of precession frame is less than ±0,5 rad.

The optimal setting for PID controllers was searched in three steps:

1. *Setting of proportional coefficients of PID feedback* (p_1, p_2)

Derivative and integral coefficients stay zero ($d_1, d_2, i_1, i_2 = 0$) in this step. We can easily see for which combination of values p_1 and p_2 is minimum of the surface plot of the first criteria (see Fig. 3). Minimum of the first criteria is for $p_2 = 100$. $p_1 = 800$ seems to be a minimal value of this parameter, for which the second criteria is also satisfied (maximal displacement of precession frame). On surface of the second criteria (see Fig. 4) it is possible to check if maximal displacement of precession frame is really less than ±0,5 rad for selected values of p_1 and p_2.

2. Setting of derivative coefficients of PID feedback (d_1, d_2)

Integral coefficients stay zero ($i_1, i_2 = 0$) and proportional coefficients (p_1, p_2) are set on values determined in previous step. Minimum of the first criteria (see Fig. 5) is for $d_2 = 25$ and probably for the highest value of d_1 (it is impossible to see in first criteria surface plot). Minimum of the second criteria (see Fig. 6) is for $d_1 = 1000$ the value on the edge of observed interval of d_1. The surface plot of the second criteria proofs previously estimated value of d_2 coefficient.

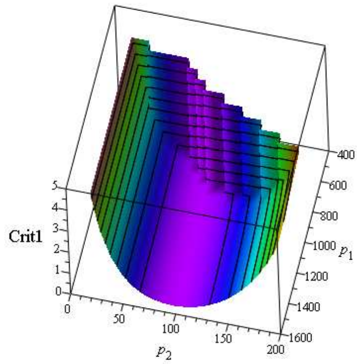

Fig. 3 Surface of 1st criteria – dependency on p_1, p_2

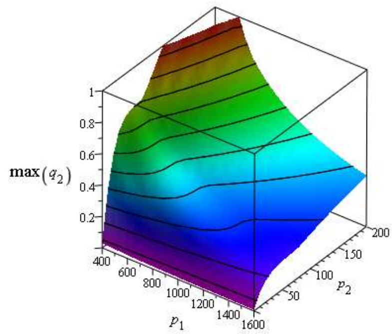

Fig. 4 Surface of 2nd criteria – dependency on p_1, p_2

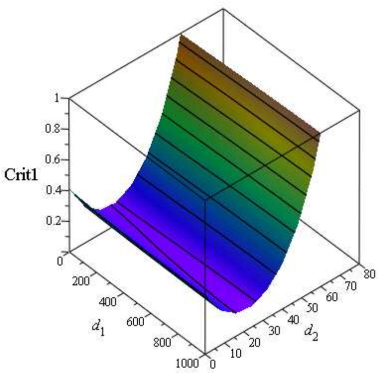

Fig. 5 Surface of 1st criteria – dependency on d_1, d_2

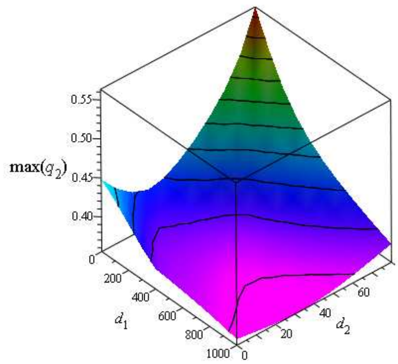

Fig. 6 Surface of 2nd criteria – dependency on d_1, d_2

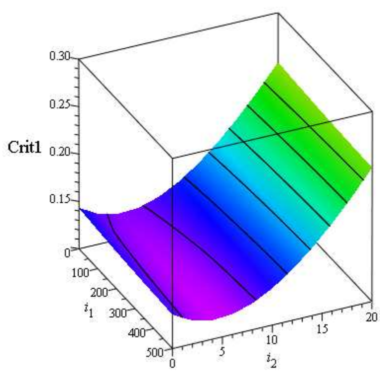

Fig. 7. Surface of 1st criteria – dependency on i_1, i_2

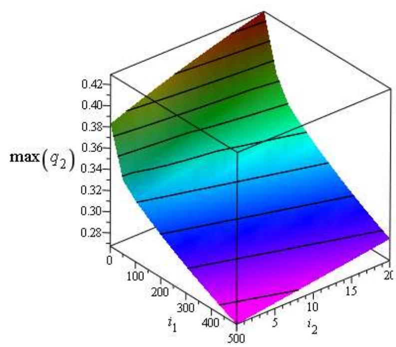

Fig. 8. Surface of 2nd criteria – dependency on i_1, i_2

3. Setting of integral coefficients of PID feedback (i_1, i_2)

Proportional and derivative coefficients (p_1, p_2, d_1, d_2) are set on values determined in the previous two steps. There is minimum of the first criteria (see Fig. 7) for $i_2 = 5$ and seems to be for the highest values of i_1. But difference between value of first criteria for $i_1 = 0$ and $i_1 = 500$ is very small thus we can say the effect of coefficient i_1 is small. It is possible to see the value of coefficient i_1 effects mainly on value of the second criteria (see Fig. 8). The maximal value of precession frame displacement is satisfactory even for $i_1 = 0$ thus we choose this value.

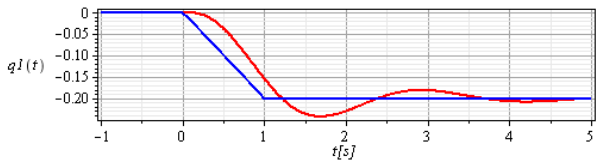

Fig. 9. Comparison of the desired time response of q_1 and time response for setting after the 1st step

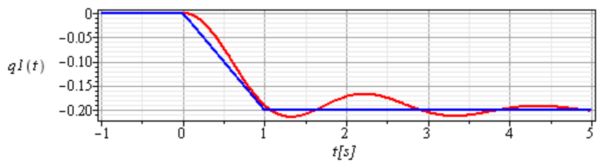

Fig. 10. Comparison of the desired time response of q_1 and time response for setting after the 2nd step

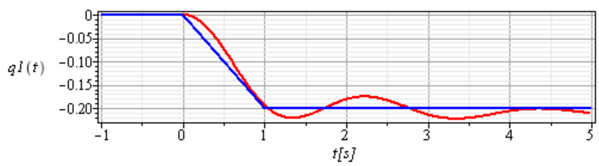

Fig. 11. Comparison of the desired time response of q_1 and time response for setting after the 3rd step

Conclusions

This paper presented determination of values of PID controller coefficients for required behavior of described mechanical system. Figs. 9-11 demonstrate effects of settings of PID controllers in each step. Values of proportional coefficients are very close to values estimated in the previous paper [1]. For different gyroscopic system and different requirements the described process of tuning of correction and compensation system PID controllers settings can be used.

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References

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